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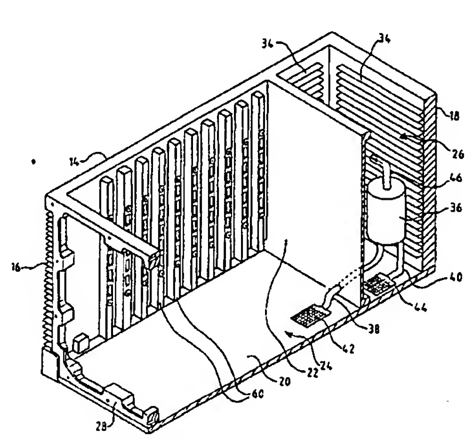
(54) Title: ENCLOSURE FOR SPRAY COOLING ELECTRONIC MODULES



(57) Abstract: An enclosure for spray cooling a plurality of circuit boards containing heat generating devices includes a chassis defining an enclosed chamber (24) that includes opposing walls (12, 14) with a plurality of rails (60) formed on the interior side of the opposing walls to define slots for receiving circuit boards. A coolant delivery system (36) includes a coolant delivery manifold in each of the opposing walls in fluid communication with a plurality of spray nozzles mounted to the rails on the walls. Each spray nozzle atomizes and discharges coolant into the chamber between the circuit boards in the slots. A plurality of apertures in the rails provide fluid communication between the chamber and a respective coolant return manifold to receive vaporized coolant from the chamber. A coolant supply system receives and cools coolant from the coolant return manifold and pumps cooled coolant to the coolant delivery manifold for delivery to the nozzles. Optionally, a sump (42) in the chamber is connected to the coolant supply system (36) to supply condensed coolant from the chamber. Also optionally, heat sinks (34) are integrally formed in the exterior sides of the opposite walls adjacent the coolant return manifolds.

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ENCLOSURE FOR SPRAY COOLING ELECTRONIC MODULES

CROSS-REFERENCE TO RELATED APPLICATION

This application claims benefit of Provisional Application No. 60/141,406 filed June 29, 1999 for "Enclosure For Spray Cooling Electronic Modules" by Steven J. Young.

BACKGROUND OF THE INVENTION

This invention relates to cooling electronic modules, and more particularly to an enclosure containing a rack supporting a plurality of heat-generating circuit boards in which the enclosure includes evaporate spray cooling apparatus for cooling the circuit boards.

Electronic circuits are often incorporated as circuit boards supported by racks formed by mounting rails in a chassis. Circuit components on the boards generate substantial heat which needs to be dissipated. Conventionally, heat is carried away by forced air convection or thermal conduction through heat plates, or both. Forced air convection involves forcing cooled air into the enclosure and over the surfaces of the circuit boards to carry away heat from the circuit components. Heat conduction techniques employ a thermally conductive layer within the circuit board, which may also serve as an electronic ground plane, to transport heat through the circuit board to an outside edge thereof, for dissipation through heat fins or the like associated with the enclosure.

One problem with forced air convection techniques is that a risk arises of introducing contaminated air into the enclosure which may adversely affect operation of the circuit modules. This problem can be overcome using a closed forced air system whereby the air exhausted from the chamber containing the circuit board is cooled, re-circulated and returned to the chamber. However, the apparatus needed to cool the air is often bulky, expensive, and a source of electrical noise, making forced air convection

techniques undesirable. Nevertheless, the cooled air forced into the chamber is heated as it passes over heated components, reducing the ability of the air to receive heat from downstream components. Consequently, components closest to the source of cooled air are most efficiently cooled, while those furthest from the cool air source are least efficiently cooled. While cooling efficiencies can be addressed in the layout of the board, addressing those issues in the board design adds to the complexity and cost of the unit, often at a sacrifice of other considerations.

Heat conduction techniques rely on conduction of heat through the heat conducting plane, such as a ground plane, within the circuit board, or in some instances through a metallic heatsink plane in communication with the circuit board. Heat is usually conducted toward a coldwall, such as the chassis sidewalls which are cooled by passing a cooling fluid, such as air, over integral or external fins. Heat is conducted through the board, passing from warmer components to cooler components resulting in inefficient cooling, particularly for downstream components. Thus, heat conduction techniques require many of the same considerations of board design and cooling efficiencies as heat convection techniques.

Evaporative spray cooling has recently received considerable attention for cooling electronic modules. This technique involves spraying atomized liquid droplets directly onto the surface of a heat-generating component. The liquid forms a thin coating on the component which is heated by the excess heat from the component and evaporated from the component surface to cool the component. The evaporated coolant is then recovered, cooled and condensed, and returned to the enclosure for continued cooling operation. Evaporative spray cooling permits uniform cooling over the entire board, eliminating hot and cold spots traditionally associated with convection and conductive cooling.

Evaporative spray cooling techniques require the coolant be atomized to tiny liquid droplets. This is accomplished by a nozzle that dispenses a fine spray of liquid droplets onto the electronic module. It is important that the nozzle be positioned

closely to the component being cooled because this spray may condense quickly. Tilton, in U.S. Patent No. 5,220,804, places an array of coolant nozzles confronting each circuit board to spray atomized coolant droplets directly onto the various components of the board. A stack comprising a plurality of circuit boards requires a similar plurality of nozzle arrays, resulting in a bulky stack, detracting from miniaturization of circuitry.

McDunn, in U.S. Patent No., 5,831,824, suggests an enclosure in which the atomizing spray nozzles are arranged in supporting rails between the boards at the top of the enclosure, and liquid recovery orifices are on the bottom of the enclosure to recover the condensed liquid. The McDunn approach has several problems. The spray patterns of the nozzles are such that coating of components distal from the nozzles is not fully assured, thus limiting the physical size of the board. More importantly, McDunn's approach requires a separate and externally located condensor component along with the necessary tubing and fittings. The additional tubing and fittings negatively impact system level reliability and the externally located components increase the burden of maintaining fielded equipment. Further, McDunn's approach implies reliance on condensation of the evaporative coolant within the enclosure to allow the recovery of the coolant in the liquid form, rather than the vapor form. Since the coolant most efficiently carries heat away from the circuits when in the vapor form, the requirement to condense the coolant within the circuit enclosure renders the McDunn approach inefficient.

SUMMARY OF THE INVENTION

The present invention is directed to an enclosure for spray cooling a plurality of circuit boards containing heat generating electronic devices. The enclosure includes a chassis, a coolant delivery system and a coolant supply system. The chassis defines an enclosed chamber and includes first and second opposing walls each having an interior side in the chamber and an exterior side outside the chamber. A plurality of rails are formed on the interior side of the first and second walls, the rails on opposite walls being in substantial alignment to define slots for receiving circuit boards. The coolant

delivery system is supported by the chassis and includes a first coolant delivery manifold in the first wall and a second coolant delivery manifold in the second wall. A first plurality of spray nozzles mounted to the rails on the first wall are in fluid communication with first coolant delivery manifold, and a second plurality of spray nozzles mounted to the rails on the second wall are in fluid communication with the second coolant delivery manifold. Each of the spray nozzles atomizes and discharges coolant into the chamber between circuit boards received in the slots. A first plurality of apertures are in the rails on the first wall in fluid communication with the chamber and a second plurality of apertures are in the rails on the second wall in fluid communication with the chamber. Each of the apertures receives vaporized coolant from the chamber. A first coolant return manifold in the first wall is in fluid communication with the first plurality of apertures and a second coolant return manifold in the second wall is in fluid communication with the second plurality of apertures. The coolant supply system is connected to the first and second coolant return manifolds and to the first and second coolant delivery manifolds to cool coolant received from the chamber through the apertures and the first and second coolant return manifolds and for pumping cooled coolant to the first and second coolant delivery manifolds for delivery as atomized liquid droplets through the nozzles.

One optional feature of the invention is a cooling reservoir connected to the first and second coolant return manifolds for providing increased heat removal capacity for cooling the coolant. A pump is connected to the cooling reservoir to pump cooled coolant to the first and second coolant delivery manifolds.

Another optional feature is a sump in the chamber connected to the pump to supply condensed coolant from the chamber to the reservoir.

Another optional feature is the inclusion of first and second pluralities of heat sinks integrally formed in the exterior sides of the respective first and second walls adjacent the respective first and second coolant return manifolds.

The inclusion of the nozzles in the rails at both ends of the circuit board, assures delivery of coolant to components more centrally located on the board, thereby increasing the size limits to the board over single-rail delivery systems, such as in McDunn. The receiver apertures in the rails receive vaporized coolant from the chamber.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an exploded perspective view of an enclosure in accordance with the presently preferred embodiment of the present invention;

FIG. 2 is a plan view of a side wall of the enclosure of FIG. 1;

FIG. 3 is a view similar to FIG. 1, partly cutaway along plane 3-3 of FIG. 1 to illustrate certain features of the coolant recovery techniques of the present invention; and

FIG. 4 is a section view taken at line 4-4 in FIG. 1 illustrating details of the side wall and manifolds of the enclosure shown in FIG. 1.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

As shown particularly in FIGS. 1 and 3, an enclosure 10 has side walls 12 and 14 each carrying external heat dissipating fins 16. A rear wall 18 and bottom wall 20 are connected to side walls 12 and 14, and a divider wall 22 is connected to side walls 12 and 14 and bottom wall 20 to divide enclosure 10 into two chambers 24 and 26. Rear wall 18 may also be configured as an input plenum for receiving forced-air cooling fluid for cooling the spray cooling coolant contained within the enclosure. For this configuration, the input plenum is in communication with heat dissipating fins 16. This communication is achieved with a shroud, cover, or wall that is attached over fins 16 to allow routing of the forced-air cooling fluid from the plenum on past fins 16. A frame member 28, connected to an end of bottom wall 20 and side walls 12 and 14, supports cover 30 closing a front portion of chamber 24. A top cover 32 is fastened to the tops of

side walls 12 and 14, frame 28 and back wall 18 to hermetically enclose and seal chambers 24 and 26.

As shown particularly in FIG. 3, chamber 26 contains a plurality of heat sink fins integral with the internal surfaces of side walls 12 and 14 and rear wall 18. Pump 36 collects coolant through conduits 38 and 40 from sumps 42 and 44 and supplies coolant through conduit 46 to inlets 48 and 50 (FIG. 2) of manifolds 52 and 54 (FIG. 4) in each side wall 12 and 14. Each manifold 52 is in fluid communication with a plurality of nozzles 56 to direct a spray 58 of atomized coolant into chamber 24. Spray nozzles 56 are mounted to rails 60 extending into chamber 24. Similarly, nozzles 62 are in fluid communication with manifold 54 in each side wall 12 and 14 to direct an atomized spray 64 into chamber 24.

Rails 60 are attached to the internal surfaces of side walls 12 and 14 and are arranged in vertical, parallel alignment to form vertical slots 66 between adjacent rails 60. Each slot 66 receives a respective circuit board 68 containing heat-generating circuits to be cooled. Each circuit board 68 includes an edge connector 70 arranged to engage a respective slot connector 72 in motherboard 74 mounted to bottom wall 20 within chamber 24. Connectors 70 and 72 provide power and signal transmission between the circuit boards 68 and equipment external to enclosure 10.

Each rail 60 also includes a plurality of collection apertures 76 in fluid communications with chamber 24 for receiving vaporized coolant and delivering and supplying the vaporized coolant to manifold 78 within side walls 12 and 14 for return through inlet 80 to chamber 26.

In operation, a supply of coolant is stored in chamber 26 and pumped via pump 36 into manifolds 52 and 54. The coolant is discharged through nozzles 56 and 62 in an atomized spray to thinly coat the heated components on circuit board 68. The heat from those components vaporizes the coolant which is received through apertures 76 and manifold 78 and returned to the coolant supply chamber 26. Any coolant that may remain in the liquid form in chamber 24, or that may condense in chamber 24, is

collected on the floor of the chamber formed by bottom wall 20 and is collected through sump 42 for delivery back to pump 36.

The provision of spray nozzles 56 and 62 on each of the side walls 12 and 14 assures a uniform delivery of atomized coolant to the circuit boards 68 supported within slots 66. Vaporized coolant is returned through aperture 76 without requiring the coolant to first condense, thereby allowing recovery of coolant in vaporized form, rather than in the liquid form as in the prior art, providing more efficient spray cooling.

In one embodiment, the system operates as a closed loop cooling system that operates due to maintaining a pressure differential between chamber 24 (high pressure) and chamber 26 (low pressure).

Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention.

What is claimed is:

1. Apparatus for spray cooling a plurality of circuit boards containing heat generating electronic devices, the apparatus comprising:

a chassis defining an enclosed chamber, the chassis having

first and second opposing walls each having an interior side in the chamber and an exterior side outside the chamber,

a plurality of rails formed on the interior side of the first and second wall, the rails on the first wall being in substantial alignment with the rails on the second wall to define slots between the rails, each slot being arranged to receive a circuit board;

a coolant delivery system supported by the chassis comprising

a first coolant delivery manifold in the first wall and a second coolant delivery manifold in the second wall,

a first plurality of spray nozzles mounted to the rails on the first wall in fluid communication with the first coolant delivery manifold, and a second plurality of spray nozzles mounted to the rails on the second wall in fluid communication with the second coolant delivery manifold, each of the spray nozzles being arranged to atomize and discharge coolant supplied by the respective first or second coolant delivery manifold into the chamber between circuit boards received in the slots;

a first plurality of apertures in the rails on the first wall in fluid communication with the chamber and a second plurality of apertures in the rails on the second wall in fluid communication with the chamber, each of the apertures being arranged to receive vaporized coolant from the chamber,

a first coolant return manifold in the first wall in fluid communication with the first plurality of apertures and a second coolant return manifold

in the second wall in fluid communication with the second plurality of apertures; and

a coolant supply system connected to the first and second coolant return manifolds and to the first and second coolant delivery manifolds for cooling coolant received from the chamber through the apertures and the first and second coolant return manifolds and for pumping cooled coolant to the first and second coolant delivery manifolds.

2. Apparatus as in claim 1, wherein the coolant supply system includes a cooling reservoir connected to the first and second coolant return manifolds for providing additional heat removal capacity for cooling coolant, and a pump connected to the cooling reservoir for pumping cooled coolant to the first and second coolant delivery manifolds.

3. Apparatus as in claim 2, wherein the coolant supply system includes a sump in the chamber and connected to the pump to supply condensed coolant from the chamber to the reservoir.

4. Apparatus as in claim 1, wherein the coolant supply system includes a sump in the chamber for supplying condensed coolant from the chamber to the first and second coolant delivery manifolds.

5. Apparatus as in claim 1, wherein the chassis further includes first and second pluralities of heat sinks integrally formed in the exterior sides of the respective first and second walls adjacent the respective first and second coolant return manifolds.

6. Apparatus as in claim 1, wherein the chassis further defines a cooling reservoir separate from the chamber, the cooling reservoir containing the coolant supply system.

7. Apparatus as in claim 6, wherein the cooling reservoir is connected to the first and second coolant return manifolds and is arranged to cool coolant, the coolant supply system further including a pump connected to the cooling reservoir for pumping cooled coolant to the first and second coolant delivery manifolds.

8. Apparatus as in claim 7, wherein the coolant supply system includes a sump in the chamber and connected to the pump to supply condensed coolant from the chamber to the reservoir.

9. Apparatus as in claim 6, wherein the coolant supply system includes a sump in the chamber for supplying condensed coolant from the chamber to the reservoir.

10. Apparatus as in claim 5, further comprising a rear wall configured as an input plenum for receiving forced-air cooling fluid for cooling coolant.

11. Apparatus as in claim 10, wherein the input plenum is in communication with the plurality of heat sinks.

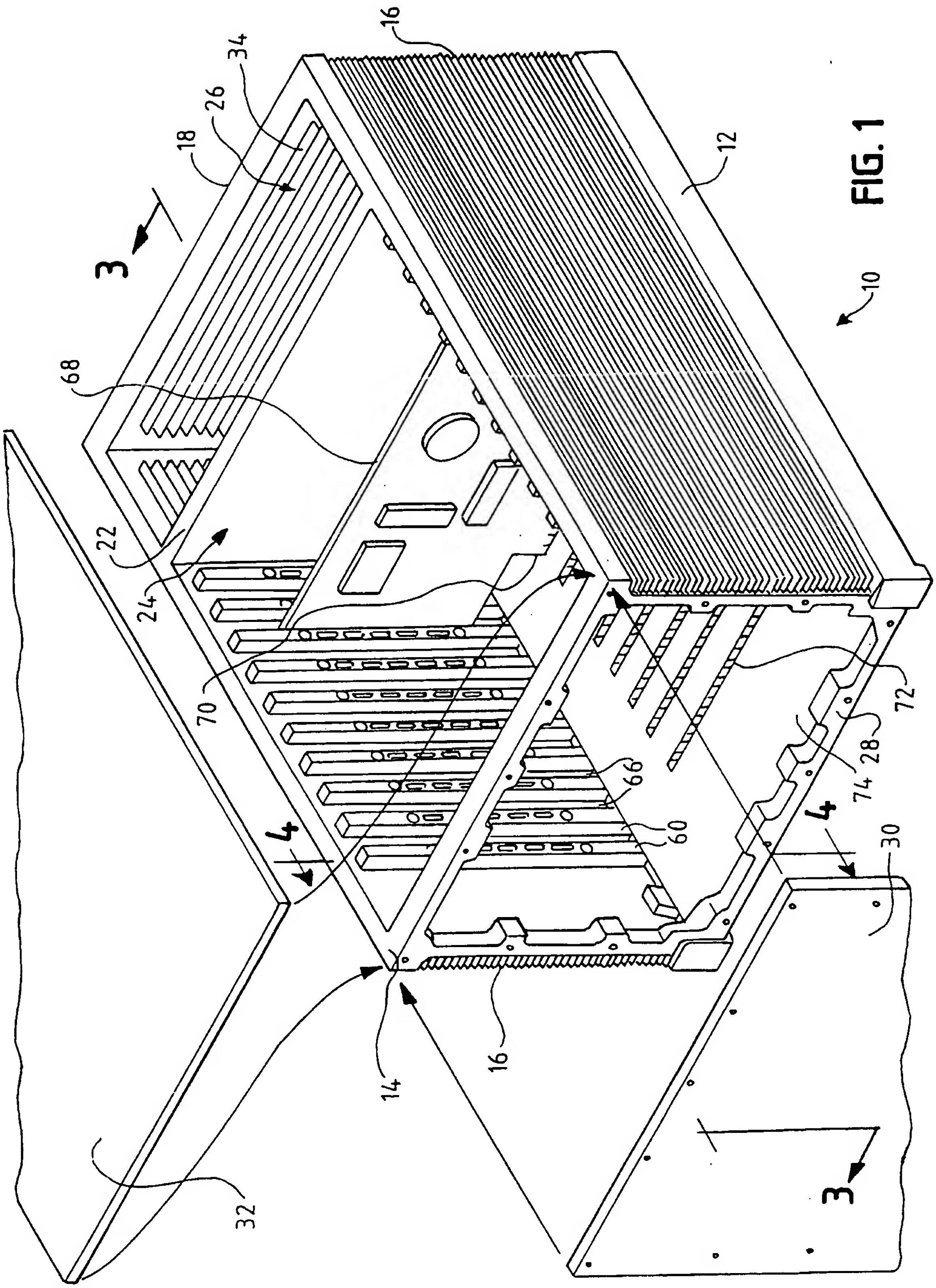

FIG. 1

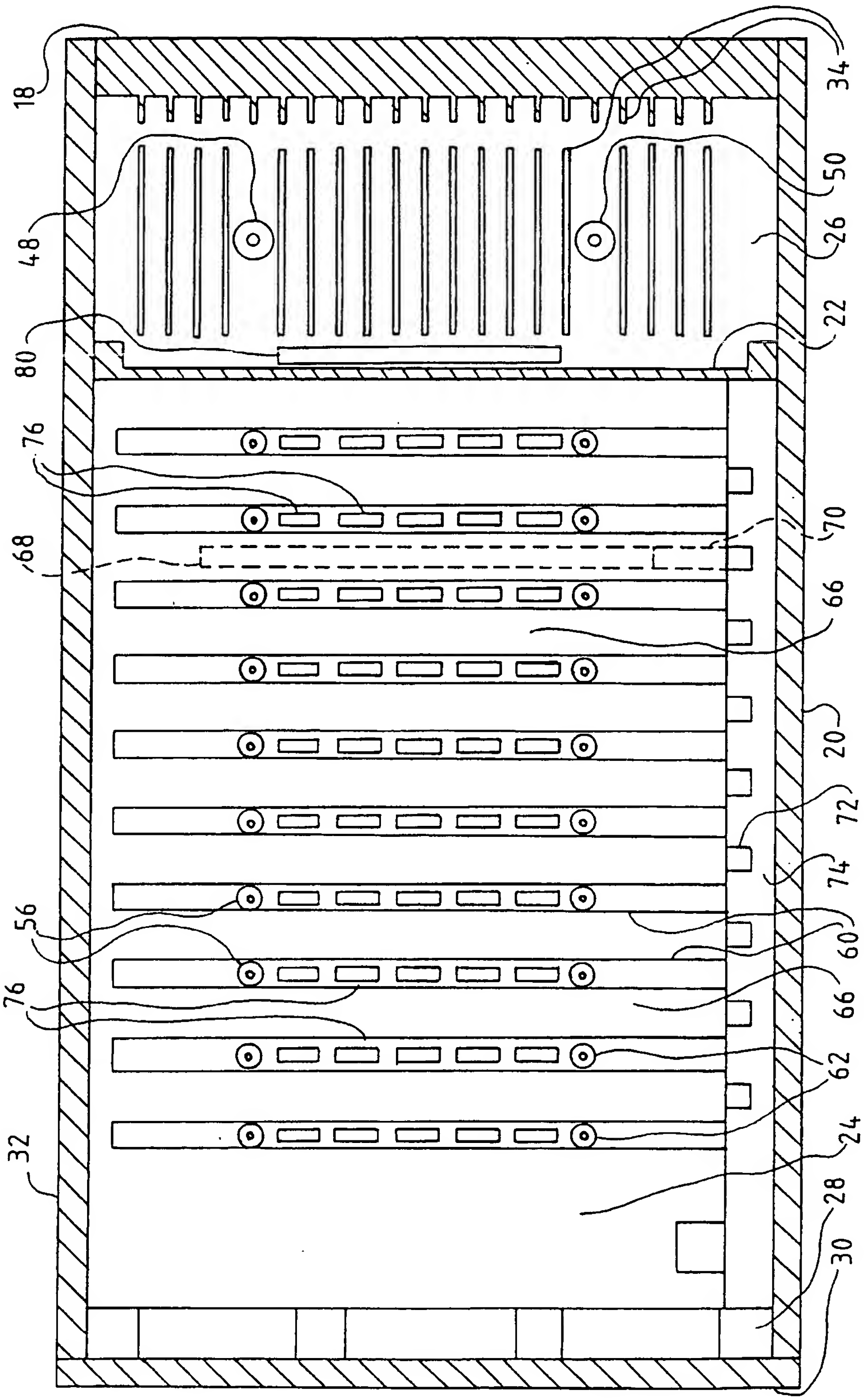

FIG. 2

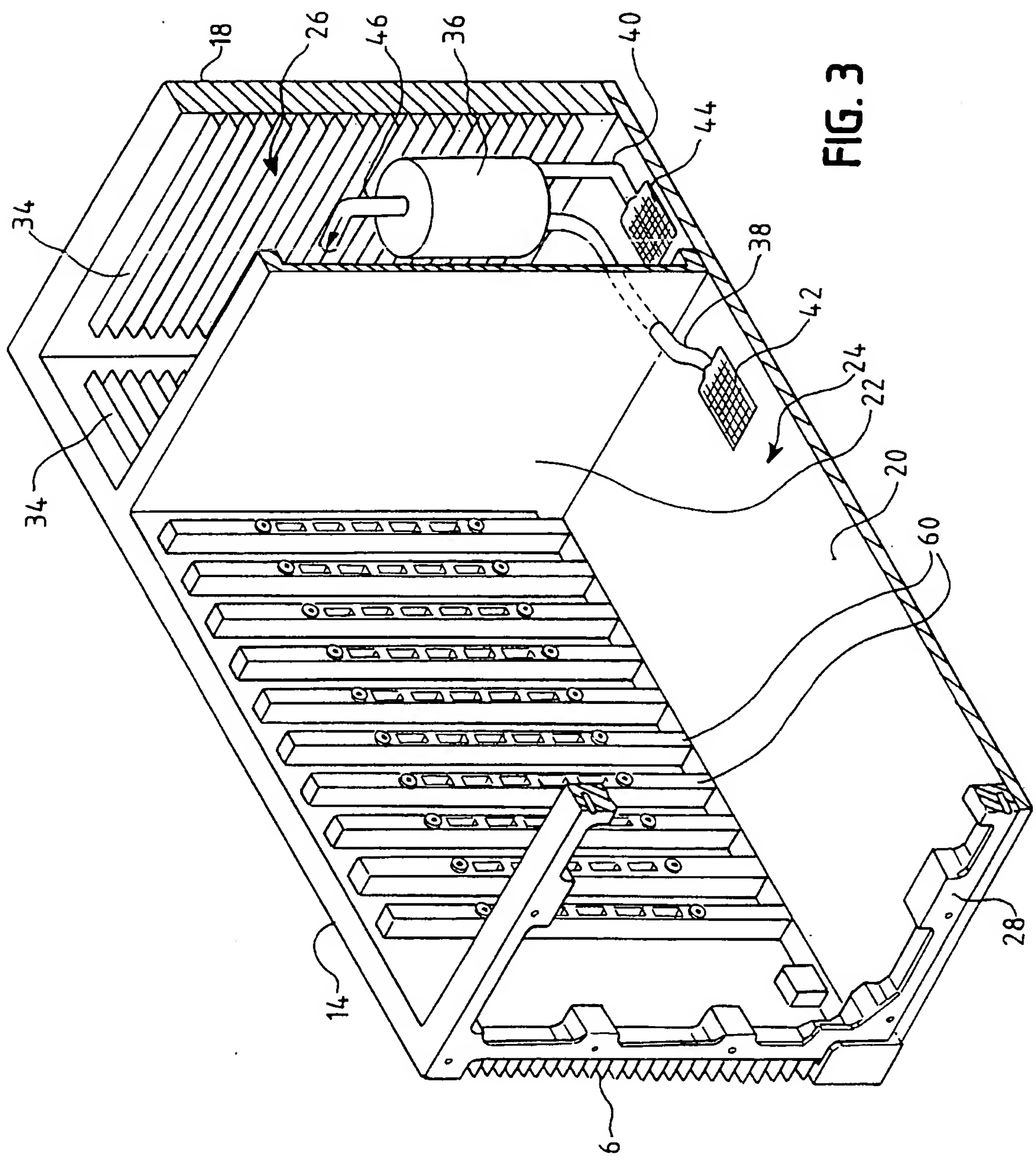

FIG. 3

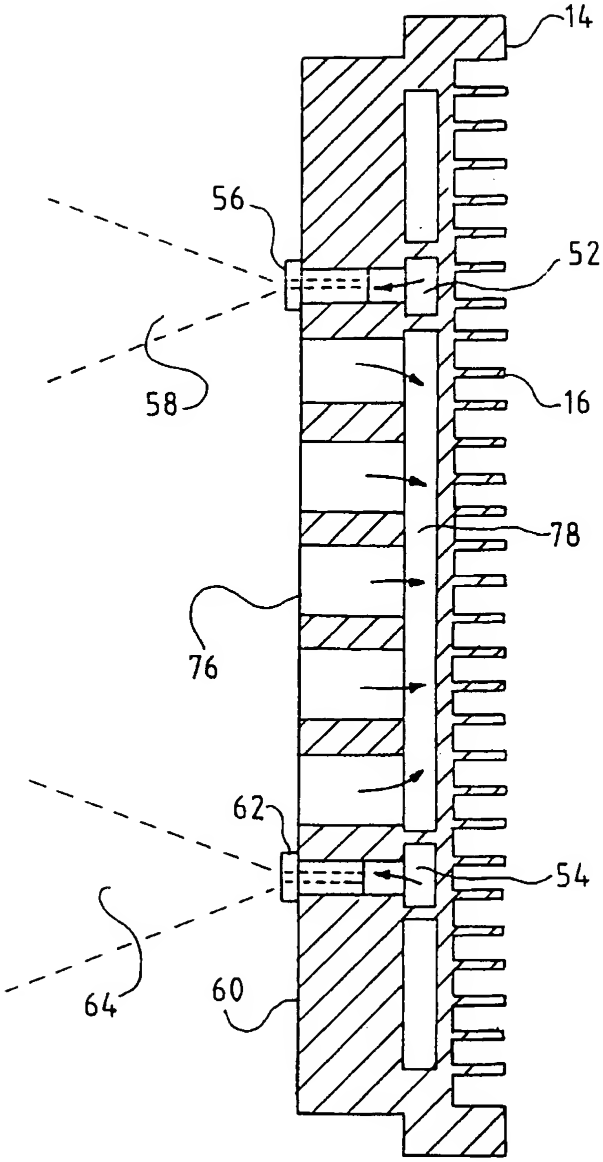

FIG. 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/17934

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) :H05K 7/20
US CL :174/15.1, 15.2, 16.3; 361/687-689, 698-703, 752, 758, 796
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 174/15.1, 15.2, 16.3; 361/687-689, 698-703, 752, 758, 796

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

none

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EAST

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,831,824 A (McDUNN et al.) 03 NOVEMBER 1998 (03-11-98), col. 6, lines 1-31	1
A	US 5,220,804 A (TILTON et al.) 22 JUNE 1993 (22-06-93), figure 11	1

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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20 OCTOBER 2000	28 NOV 2000

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